DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

PROBLEMS OF PROGRESS IN INDUSTRY—9

AUTOMATION AND SKILL

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PREFACE

The object of this series is to present briefly and simply the results of new research into the economic, technical and human problems of industrial progress—problems arising from automation and other advances in techniques, and problems of management and social relations.

The series is commissioned and edited by the Department of Scientific and Industrial Research, which seeks to provide a forum for responsible new thinking and to stimulate independent discussion and action, including future research. The conclusions are those of the investigators, mostly from the universities and other well-known research bodies.

The Department recently sponsored a study of the human implications of Automation. This was carried out under the direction of Mr. A. T. Welford, and included a critical appraisal of research findings and a survey of existing practice in industry. The present issue gives an account of the industrial survey, and discusses the skills required of human operators in highly-mechanized and automatic plants, as well as problems of selection and training.

In a previous issue of this series, 'Ergonomics of Automation' (Problems of Progress in Industry No. 8) Mr. Welford reviewed research relevant to the problems of the human operator in an automatic plant, with special emphasis on the design of equipment.

The two booklets together constitute the final report of this study.

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CONTENTS

INTRODUCTION

The spread of automatic methods in industry and offices greatly affects not only productivity and methods of organization, but also the demands made by work on individual men and women.

A brief outline of changes in operative skills was given in the DSIR report on Automation,[1] where a common trend was noted 'towards supervision rather than direct manipulation of the process, and towards skill based on knowledge of plant and equipment'. The emphasis was shifting from manual skills to those based on 'the ability to take in information and to organize and interpret it for action'.

Little was known then about the precise nature of these new skills, how far they would be of general or specific application in industry, and what effect they would have on selection and training. To find answers to these problems, DSIR sponsored a study, and this booklet is a summary of some of its results.

INDUSTRIAL SURVEY

The study was based on visits to factories and plants representing different types of technical advance. They included factories manufacturing motor-cars, valves, cigarettes, textiles, instruments, electrical equipment for motor-cars, heavy electrical equipment, paint, biscuits, margarine, a heavy chemical plant, an oil refinery, a board mill, a steel works, a liquid-oxygen plant, a brewery, electricity generating stations, an electricity distribution centre, a railway electrical control room, and an electronic computer in business use. The visits were mostly short, but on a few of them it was possible to spend some hours recording operators' activities and discussing their work with them. Shift or departmental managers provided most of the information about plant operation and its demands on the operator.

The work and skills were studied from the standpoint of an experimental psychologist, rather than that of an industrial manager: interest was directed at the present abilities and performance of operators, and how they achieve their results, rather than at their formal training and experience. Psychologists use the term 'skill' for any particular ability, from dexterities and

knacks to complex decision-making; whereas when industrialists talk of a 'skilled man', they usually mean one who has undergone a certain training or apprenticeship which is needed for the job in question. The industrial reader should bear this important distinction in mind.

I. THREE TYPES OF AUTOMATION

The starting point for the survey was the threefold classification of automatic techniques adopted in the DSIR report—transfer machines and automatic handling; automatic process-control; and electronic computers in offices. While this breakdown is useful in relation to technology, it proves inadequate from the standpoint of the demands on the operator; the following breakdown is more helpful:

1. *Continuous-flow production.* Transfer-machines and automatically controlled processes have been grouped together. Though technologically very different, they both represent a similar advanced level of industrial development. The skills needed by the operators in these very different industries are surprisingly alike, though several sub-patterns (which will be discussed later) can be identified within the broad picture.

2. *Programme-machines.* Computers in offices stand alone, not so much because they are fast and automatic, and produce information rather than goods, as because they are very flexible. They can be made to do quite different classes of work in quick succession by inserting different 'programmes'. Electronically-controlled machine tools also have this flexibility. They seem likely to make broadly similar demands on operators, though at present these are difficult to assess because there are still very few of these machines in everyday use.

3. *Centralized remote control.* Centralized remote control is typified by the modern railway control centre. Such centres are of growing importance in public services such as transport and communication, and may well become important in manufacturing. Their common characteristic is that the operations being controlled, are inaccessible to the operator and so must be handled in an artificial setting.

Remote control is also found on continuous-flow production, for instance, in process-control rooms and continuous strip-mills, but, as the operator can view these operations directly, the demands are less severe.

In the following chapters an attempt is made to outline the essential features of work and skill under these headings; to provide a framework of thought for those whose job it is to select, train and employ workers in automatic industry; and to forecast some of the future developments to be expected. While the emphasis is on individual skills, brief mention is made of responsibility and of the working environment.

II. CONTINUOUS-FLOW PRODUCTION

It has been pointed out [(2)] that manufacturing methods in an industry usually pass through three stages of technical advance: first, small-batch and 'unit' (i.e. one-off) production, where craftsmen predominate; second, large-batch and 'mass' production, with many semi-skilled workers; and, third, continuous-flow or 'process' production. Different industries reach the stages earlier or later according to the severity of their technical problems.

Flow production was first achieved some time ago in the so-called 'process' industries, such as chemicals and oil, where the raw materials are particularly suitable for continuous handling and processing. More recently the difficult technical problems of mechanical handling and automatic processing have been solved for the making of separate articles, for example pistons, cylinder blocks, glass bulbs, cigarettes, cardboard boxes and so on. As a result it has become possible to manufacture them automatically, i.e. without needing an operator to start each cycle of the production process. This is automatic *operation* and should not be confused with automatic *control*, which is a later development.

The change to automatic operation brings a considerable change in the demands on the operator from those made by the repetitive work characteristic of 'mass' production. But the jobs, though new in their context, closely resemble process-work as

performed in a conventional chemical factory, for the operator has to monitor and adjust a continuously running process, making no direct contribution to its sequence of operations and speed of action.

Although production can continue without him for a time, the operator's presence is still essential. His job is to maintain quality and avoid breakdowns, a function which was carried out piecemeal when the various operations were done on separate machines, but which in the new plant is handled by one man, whose actions affect the quality of a much larger output. In short, he is a 'controller', rather than a 'producer'.

All observers agree that manual skills needing co-ordination of hand and eye (often called 'sensorimotor' skills) are much less important under automation, and the findings of the survey endorse this view. Some observers say that they are replaced by conceptual skills, meaning that operators who monitor larger and more complex machines have more difficult observation and thinking to do in proportion to their physical effort. But others claim that the new processes require virtually no skill, and that the operator is simply a 'machine-minder', kept on the plant to record instrument readings and call for help in emergency. Both types of situation were seen during the survey, for the variety of monitoring, machine-minding, and process-operating jobs in automatic industry is almost as great as the variety of manual operations in conventional factories.

Table 1 shows the main distinguishing characteristics of the various continuous-flow processes seen during the survey.

While, in principle, the characteristics shown in the table can be combined in many ways, most of the plant seen during the survey fall into only four groups:

1. Large manually-controlled plants* making a continuous product by a predominantly chemical or physical process. There are several operators, each in charge of a fairly small part of the plant, and success depends not only on the ability of each operator but also on the co-ordination of the team as a whole. Individuals have

* These plants are not commonly included under the heading of automation, but the demands for skill made by the other groups can best be understood in relation to them.

TABLE 1. CLASSIFICATION OF AUTOMATIC PLANT

Relative Size	
Large	several operators to one plant. (For example: board-mill, chemicals, oil, electricity etc.)
Small	one operator to one or more machines. (For example: cigarette-making, weaving, automatic lathes etc.)
Product	
Continuous	materials *flow* through the plant; it is usually wasteful to stop and restart the process. (For example: board-mill, chemicals, oil, electricity, many foodstuffs, paint, glass etc.)
Separate articles	materials transported mechanically, the process can usually be stopped and restarted easily. (For example: transfer-lines for cylinder blocks and pistons, packing machines, printing presses etc.)
Control	
Manual	the operator directly controls the process and is responsible for making all running adjustments. (For example: board-mill, older atomic energy plant, weaving, printing etc.)
Automatic	the operator sets desired running conditions and automatic devices ensure that they are maintained. (For example: new chemical and atomic energy plant, oil-refineries, newer boilers etc.)
Type of Process	
Mechanical	the process consists of mechanical actions such as cutting and shaping. The operator can easily visualize what is happening. (For example: transfer machines, final stage of glass-bulb making, packing, knitting etc.)
Non-mechanical	chemical, physical or other processes where the operator cannot easily visualize what is happening. (For example: chemical, electricity, plastics, some foodstuffs etc.)

a good deal of detailed control work to do, but few complex decisions to make.

2. Plants similar to (1) but with automatic *control.* Individuals have much less detailed control work, but usually more complex decisions to make.
3. Transfer-lines—sequences of mechanical operations such as cutting and forming, performed by self-acting machine-tools with a regular cycle of operations, and automatic transfer from one to the next. Operators are there principally to feed in workpieces, maintain control of dimensions, and repair breakdowns.
4. Relatively small continuously-running machines that can be controlled by one operator. Usually a number are grouped together, and one operator may be given charge of several machines.

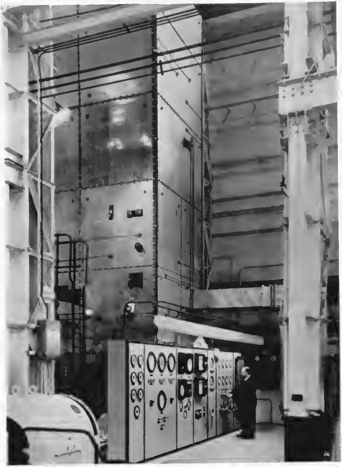
The demands of each of the four groups on the operators will now be described in more detail with several examples. The general characteristics of continuous-flow plants will be outlined in relation to the first group, and the special characteristics of the other three will then be taken in turn.

LARGE PLANT UNDER MANUAL CONTROL

The first group comprises the large process-plants, automatic in operation but not automatically controlled, where the work is typical 'process-work'. The first example comes from a long-established process industry which would not ordinarily be regarded as having 'automation', and where recent technical change does not distort the picture. It does, however, represent a very high level of technical development in large-scale production.

Case 1. The column-operator in a liquid oxygen plant

To make liquid oxygen, air is drawn from the atmosphere, compressed and liquified by an expansion engine. The oxygen and nitrogen are then separated in a distillation column at temperatures around —180°C. The nitrogen returns to the atmosphere and the oxygen runs into an insulated storage tank. Rare gases—argon, neon, and krypton—can also be obtained from the distillation column if required.



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The distillation column of a modern liquid oxygen plant. One operator has sole charge of the plant.

A plant producing liquid oxygen equivalent to some 15 000 cubic feet of gas an hour is controlled by two men, the compressor- and the column-operators, and it is run continuously on a four-shift system. The column-operator's job is to control the column to give liquid oxygen at least 99·5 per cent pure, with the minimum waste of oxygen gas to the atmosphere; he may sometimes be asked to produce rare gases. He must be able to start up the plant, and shut it down in emergency or for maintenance, without causing permanent damage or undue waste of material or power.

The column-operator cannot see the process he is controlling, and relies on some 20 pressure, temperature and flow gauges for a knowledge of its behaviour. He can also draw off a sample of the product and analyse it for purity, which he usually does every hour. He has some ten valves for controlling flow, pressure, and temperature at different points. During normal running he logs instrument readings every hour. He also has some routine maintenance to perform.

In the factory visited there were several plants of different size and age; the operators knew them all, were able to switch from one to another, and quite often did so. A shift foreman had charge of four pairs of operators and there was a works foreman on the day-shift. There were also several maintenance craftsmen and some labourers on each shift.

THE WORK OF THE PROCESS-OPERATOR

The process-operator's duties on a typical continuous-flow plant fall into four categories, as illustrated by this example.

(i) *Control.* He must monitor the various gauges, attend to the signs coming from the plant itself, such as noises, smells and vibration, and occasionally carry out special tests on the product. According to his interpretation of these indications, he must adjust the controls when necessary so as to keep the product within specification, and correct any chance disturbance or drift. Apart from the 'official' controls, there are often special ways of influencing the process, such as propping doors open to give greater cooling, or tapping pipes to loosen deposits.

Most processes require several more or less independent variables to be controlled at once, so the operator usually has to divide his attention between several activities, and he generally carries out a regular patrol of the various indicators, making adjustments where necessary.

The components of the control task may vary widely in difficulty. At one end of the scale is the simple task of keeping a single variable at a desired value by means of a direct control, e.g. maintaining a flow by opening or closing a valve. At the other end, an operator may have to maintain a combination of qualities in the product by a complex balance of conflicting requirements, as in the board-making plant described on page 18. The amount of work presented by a given control task varies widely, depending mainly on the degree of spontaneous variation in the running of the plant, together with the fineness of the control required.

In many plants, the product is changed from time to time without stopping the process, and then the operator must quickly re-adjust the process to the new specification so as to waste as little raw material as possible in a sub-standard product.

Control duty also requires the operator to be on the lookout for early signs of trouble to come, so that he can take preventive action. An acute operator may save large amounts of material and money by this means alone.

(ii) *Special procedures and drills.* There are usually set sequences of manipulation to be carried out when starting up or shutting down the plant or in particular emergencies. They are often rapid and complicated manual operations, interspersed with some control activity.

(iii) *Routine maintenance.* This may include oiling pumps, keeping the machine stocked with secondary materials, and cleaning inside vessels when they become clogged.

(iv) *Recording and reporting.* The readings of important indicators and gauges, control settings, and the results of special measurements are logged at regular intervals, and any disturbances or changed conditions are noted when they occur.

Apart from keeping written records, operators must also pass on information to their colleagues and to management by word of mouth. This is important in order to co-ordinate the operation of the various sections of a large plant.

Comparison with work in batch- or mass-production factories

Production workers in non-automatic factories usually work to a set cycle, with occasional ancillary jobs. They carry out definite operations on recognizable workpieces, and the results of their actions are immediately apparent. Speed is of primary importance since it directly governs output.

By contrast, in automatic factories:

(i) There is no definite work-cycle, usually little need for physical exertion and no emphasis on speed. The operator acts as and when he judges it to be necessary. In many cases he is free to move about the plant much of the time, but he can never leave it unattended for long at a time; he needs a relief for meals, and in case of sickness.

(ii) On the other hand, there are occasional periods of intense effort, for instance on start-up, or shut-down, or when breakdowns have to be repaired.

(iii) Each supervisor has charge of fewer operators, yet there is often less direct supervision because of the greater distances between work-places.

(iv) The operator has more contact with technical staff and managers. He is more often asked for information about his plant, and is treated more as a member of a team than his counterpart in non-automatic workshops.

(v) Shift-work (either three shifts on plant running five days a week, or four shifts continuous) is very much more common because of the high capital cost of plant and/or of waste of materials involved in shutting it down. This means more responsibility for the operator on evening and night shifts when there are fewer engineering staff on call.

(vi) Financial incentive schemes based on work-measurement ('piece-work') are rarely applied in continuous-flow plants, whereas they are common elsewhere in industry.

(vii) Employment tends to be more stable, because production is planned for years ahead. Hence there is a greater sense of security.

(viii) Women are rarely employed in automatic plant. This is mainly because of shift-working but also partly because control work seems to be more suited to men.

Despite these differences operators of automatic plant usually have a background similar to that of semi-skilled men employed on mass-production. They are recruited from the general pool of unskilled labour and have no more than a minimum of formal education. On the whole they are paid about the same, though there is little opportunity on continuous-flow plant for the occasional very high earnings made on piece-work.

PROCESS-OPERATOR SKILLS

The skills exercised by a process-operator are not obvious. It is impossible to gain an impression of them from a few minutes' observation, as one can with a semi-skilled worker. One can see very little going on in some plants; the operator watches his gauges or inspects the plant, makes an adjustment from time to time, and occasionally talks to a colleague or a manager. There is no means of assessing his skill from these activities alone.

To gain a proper perspective, one must first ask the question, what is the operator trying to achieve—or, perhaps better, what does management want him to achieve? There are five possible answers to the second question, according to the type of plant or process.

(i) Keep the process running as nearly as possible at a given condition. (*Regulation* or *Stabilization*.)

(ii) Adjust the process to give the best results according to certain criteria, e.g. yield, quality, minimum use of power, least lost time. (*Optimization*.)

(iii) Make changes from one product to another quickly and economically. (*Changeover*.)

(iv) Avoid breakdowns as far as possible.

(v) If a breakdown should occur, regain normal running as soon as possible, and minimize loss of material or risk of serious damage.

It may be possible to assess an operator's skill in these respects from plant records, but many other factors besides his performance affect the operating results in most practical cases, and a complicated statistical analysis is needed to single out the operator's effect on them, be it favourable or non-favourable.

However, it seems clear from subjective assessments, that individual operators do differ widely both in their speed of learning new control jobs and in their final level of ability. An

individual who is good on one criterion tends to be good on all, so there does seem to be a common factor or *control* skill underlying all of them (except possibly speed of repairing breakdowns). Without resorting to statistics, an individual's control skill on a given process can perhaps best be assessed by observing the speed and smoothness (or otherwise) of changeover from one running condition to another. Operators seem usually to acquire control skill on one plant or process only and cannot transfer to another without re-learning; the skill is *specific* to the situation in which it was acquired.

Analytic study suggests that a specific control skill comprises five components:

(i) *Sensing*—the ability to detect the signs and indications such as noises, smells and appearance, which indicate how the plant is running.

(ii) *Perceiving*—the ability to interpret these signs and the instrument readings in relation to one another, and to infer what is happening.

(iii) *Prediction*—of what is likely to happen in a given situation if the controls are left alone.

(iv) *Familiarity with the controls*—knowing what means can be used to influence the process, what their effects are, and how they interact with others.

(v) *Decision*—the ability to select the control action most likely to achieve the desired result in the given circumstances or to avert unfavourable developments when they threaten.

This last item, decision-making, is the central feature of the skill. It can be carried out in several ways:

(i) The operator may follow a 'rule of thumb'— doing what has always been done in a given situation, or what worked last time; but this allows little flexibility.

(ii) He may use a 'mental model' or idea of the process, on which he can try out the different possible control actions in his imagination and pick the best bet. A good operator seems to 'feel' his way into the process, becoming *intuitively* aware of what is going on and what to do about it.

(iii) The operator may use a logical approach and consciously reason out the meaning of things, analyse the situation, and come to a *rational* decision.

On the whole, discussions with operators have suggested that the first, or 'rule of thumb', method is common among the less good operators, and the second, or 'intuitive', method is often characteristic of the better ones. But few operators seem to use a fully rational or conceptual approach. So it is a little misleading, as has been suggested[i], to regard control skills as 'conceptual' if conceptual is taken to imply conscious reference to general principles; they are perhaps better described as '*intuitive*'. But further study may modify this conclusion.

A plant operator needs to know a good deal about the plant and its nomenclature, the raw materials and products, the rules for its operation, and so on. These can be taught 'off the job', whereas the control skill itself cannot. While an operator can soon learn to control a plant by following rules, the intuitive understanding which enables him to deal with subtle changes and unusual situations seems to come with experience alone.

Difficulty of control jobs

It is particularly difficult to control processes

(i) where several display and control variables depend on one another;

(ii) where the process has a long 'time-constant'—that is, takes a relatively long time (minutes, hours or even days) to settle down after a disturbance or alteration of control settings;

(iii) where important variables have to be estimated by the operator rather than measured by an instrument;

(iv) where the readings of instruments at widely separated points have to be collated; and the operator has to remember one while going to another ('short-term memory');

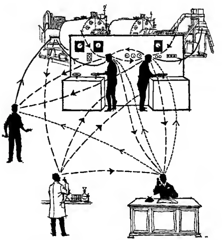
(v) where the operator gets imperfect knowledge of the results of his performance, or where the knowledge arrives late (this is a very common condition);

(vi) where the basic process is either difficult to visualize, for example chemical reactions, or contradicts 'common-sense' assumptions, or is too complicated to be held in mind at one time.

STATUS OF PROCESS-OPERATORS

Many process-plant operators appear to exercise more influence in the factory than their formal training would warrant. This

seems to be because they form an essential part of a fairly small operating team. The management relies on them for information about the plant, and they have to co-operate closely with maintenance and laboratory staff, as well as their superiors, on topics related to the process. (Fig. 1 shows this diagrammatically.)



OPERATING ——— GIVING INFORMATION — — — GIVING INSTRUCTIONS - - - - - -

The operators study the plant, and operate its controls. They pass information to the management, to maintenance workers and to one another; they receive reports from the laboratory. The managers collect information from operators and from direct inspection; they issue instructions to operators and to the maintenance staff, who carry out repairs. The laboratory staff collect samples from the process and pass their results to the operators and to management. Thus plant operators are near the centre of the communication system, providing the only direct continuous link between the plant and its various services.

Communication between members of the operating team in a highly mechanized plant

Figure 1

Perhaps because of this, they have a more responsible attitude to the job than is usually found among semi-skilled workers. They seem to recognize that 'the plant must be kept running at all costs'. A sense of responsibility is also fostered by the greater stability of employment in highly mechanized industry.

Case 2. The machine-man in a board-mill

Another example of a large plant under manual control is a board-mill, where very little automatic control has been introduced. This serves to illustrate a somewhat different kind of control work—where a large plant has many variables, but the process is largely visible and obeys common-sense mechanical principles. The major difficulty arises from the lack of a direct

The 'wet-end' of a modern board-mill. The machine-man, seen at the drive-control desk, has charge of this section of the plant, with one assistant known as the felt-boy.

measure for important process variables, and from the delay of several minutes in getting information on the results of control actions.

Cardboard is formed from a suspension of wood-fibres in water by several 'moulds'. Each mould is a rotating drum made of stainless steel mesh, and it deposits a thin layer of fibre on an endless band of felt. The wet board is removed from the felt as a continuous sheet, pressed, dried by passing through heated rolls, and reeled. A typical board-mill runs at 150–400 feet a minute, producing three

to eight tons of board an hour. The whole process is supervised by a foreman and about 22 men on each shift, roughly half of them being employed in the 'beaterhouse' preparing the stock from waste paper and wood-pulp, and the other half on the 'making' machine and its auxiliaries. When running normally the machine itself is controlled by a 'machine-man' and his assistant, the 'felt-boy', who control the 'wet-end' where the board is formed, and a 'dryer-man' on the 'dry-end'.

The machine-man's job is to keep the 'making' process going, which requires that the board should adhere to the felt, and should not break under the traction between the rollers of the successive presses. The board leaving the machine must meet a given specification of weight, thickness, moisture, strength, and appearance, and economical operation of the mill demands that the speed should be as high as is consistent with quality. This means that special care is needed to avoid frequent breakdowns.

The machine-man exercises control by adjusting the stock flow, stock depth and suction on each mould, the machine speed, pressure and 'draw' between rolls and so on (about 100 controls in all). His principal sources of information are the appearance of the liquid in the 'making' vats and the manner in which the board runs between the rollers, though there are altogether some 50 dial indicators and seven graphic recorders on the plant. Measurements of the weight, thickness and moisture of the finished board become available about six to ten minutes after its formation, and they are the final criteria of quality. The difficulty of the machine-man's job depends partly on the quality of the liquid stock arriving at the machine from the beaterhouse.

On completion of an order, the machine is kept running and must be readjusted to specification for the next order as quickly as possible. Speed is essential as the board produced during readjustment has to be scrapped. If a break should occur at any time, the board goes to waste while it has been re-threaded through several hundred feet of drying rolls. The mill runs six days a week, and the Monday-morning shift has to start it up from cold.

LARGE PLANT WITH AUTOMATIC CONTROL

The introduction of automatic control over process variables reduces the amount of routine control work to be done by the operator, but considerably complicates the decisions he must take.

In modern process plants overall control is achieved by installing a recorder/controller to stabilize each important variable, such as flow-rate and temperature, at different parts of the plant. The controller gets its information from a sensing device which registers it on a graphic recorder and activates a control element (valve, heating element, etc.). The operator sets the required value (set-point) by adjusting a second needle on the graphic recorder, and thereafter, whenever the quantity departs from the set value, the controller operates to bring it back again. The operator sets up a combination of set-points according to previous instructions or to his own judgement, and he has then only to check the recordings occasionally to ensure that the automatic controls are working correctly.

Case 3. Organic chemical works: solvents unit

The current use of automatic control may be illustrated by reference to a plant producing solvents in an organic chemical factory. Over the last five years this plant has been improved by the progressive introduction of automatic controls for temperature, pressure and level in various plant elements. These controls have now been installed in a central control room where 70–80 per cent of the process operator's work can be performed.

The raw material for the unit is vaporized, superheated and then passed through a catalytic reaction chamber in an oil-or gas-fired furnace, where it is converted into the main product (the solvent), a permanent gas and several other by-products. The gas is separated, scrubbed free of residual organic material and passed into a gas main for subsequent use in other parts of the factory. The solvent, together with the other by-products, is then passed through a series of distillation and washing columns, which separate the various constituents leaving a pure product, which is finally pumped into bulk storage tanks.

This plant is managed by a team of four process-operators on each of three eight-hour shifts. The team comprises

a leading hand, who is a working chargehand and supervisor of the complete unit, and three process-operators each of whom is responsible for one section of the plant. The leading hand is the co-ordinator of the system and is informed by the other operators whenever different sections run into difficulties. An important subsidiary activity of the leading hand is to train new operators in plant operation.

An operator at work in the control-room of a modern organic chemical plant. The small rectangular objects are recorder/controllers for various process variables and the larger one is a multiple temperature recorder.

One man, termed the furnace-man, looks after the furnaces and is responsible for adjusting their temperatures to an optimum, which varies with the state of the catalyst and with the throughput of raw measure. He also takes care of shut-downs, furnace-relighting, periodical reactivation of the catalyst, and changes of fuel. The furnace temperature is adjusted by altering the set-point of the appropriate recorder/controller, and by adjusting dampers in the flue-gas streams. He is expected to regulate the furnace temperature by hand if the recorder/controller develops a fault. Each furnace has two other recorder/controllers which the furnace-man adjusts as required.

One controls the vapour feed to the catalyst chamber, and the other the flow of water to the gas scrubber. There are also about ten indicators for other plant variables on the furnace-man's panel.

Another man, known as the 'still-man', is responsible for the solvent-distillation section of the plant. This consists of a number of distillation columns and washing columns, with their heat-exchangers and intermediate tankage. The distillation columns are controlled by several recorder/controllers for each column, governing, among other items, the feed to the column, the rate of reflux and the temperatures at various points. The still-man adjusts the set-points of these instruments to achieve steady operation within specified limits. He is also expected to operate the plant manually if an automatic controller becomes unserviceable. An important part of his job is to patrol the plant and check it for visible faults, such as fluid leaks and blocked steam traps. He also has about thirty instruments indicating various plant conditions on his panel in the control room. There are few manually operated controls on the plant itself.

Laboratory analyses of plant products are carried out at two-hourly intervals and the results are reported to the process team. More than twenty different variables are measured and the leading hand can ask for a repeat analysis of any item that differs from expectation or that he wants specially checked, perhaps because of an alteration made to the setting of the plant. Every effort is made to see that results of the analyses are not more than an hour old when they are reported to the process team.

Important process variables are recorded by the appropriate hand every hour. The hands keep a diary of abnormal conditions and an 'unserviceability book' in which they note the occurrence of any fault and subsequent action taken.

WORK OF THE PROCESS-OPERATOR

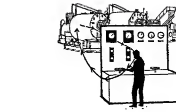
Automatic control is usually introduced to maintain more accurate and stable conditions in a plant, rather than to save labour, though

it may occasionally replace a man on a very routine control job. However, automatic control has made it possible to operate some processes which could not be run by unaided human control.

The instruments themselves are usually located in a central control room. The operator has to collate readings on instruments in the control room with conditions in the plant outside. This tends to complicate the work, though the physical conditions are improved. Further he must understand the operation of the sensing devices and control mechanisms as well as the process itself. The adjustments themselves, though they demand less frequent attention, require a higher level of thought since the effects of recorder/controllers, as well as process variables, must be considered when attempting to diagnose a fault or account for a departure from specification. In a sense one may say that his work is carried out at two removes from the actual materials being processed (see Figure 2) rather than at one remove, as in a manually-controlled plant.

In those few cases where the action of the plant has been fully analysed and planned by engineers, the need for control skill has been virtually abolished; but in many cases this point has not yet been realized and the operator can still make an important contribution to efficiency. Contrary to what is often believed, the level of vigilance required is not unusually high, as safety devices and alarms are always fitted to cater for all potentially dangerous contingencies. Other duties include keeping records, maintenance, and the use of start-up, shut-down and emergency procedures.

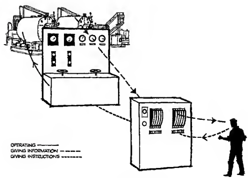
In the larger automatically-controlled plants in the oil industry, as in this example, each member of a team of several operators, the 'oil-man', 'cat-man' etc., is responsible for one section of plant under a 'still-man', who combines the functions of process-operator for the whole unit and charge-hand. The operators act as his assistants, checking the instruments and plant to ensure that the settings decided on are maintained, and detecting faults such as steam leaks, mechanical failures and variations in feed stock to either the plant or its furnaces. They do not often have to make adjustments on their own initiative. In case of emergency they work as a team under his leadership.



(a) *Manual Control*

The operator receives information about the process directly and from instruments; he maintains correct adjustment by operating the controls—he 'closes the loop', adapting his mode of control to the current situation.

In taking control decisions, he must consider the action of instruments and controls together with the plant itself.



(b) *Automatic control*

The 'loop' is now closed by an automatic controller which keeps the process in a set condition. The operator monitors the result produced by the controller, adjusts its set-point as required, and may 'trim' the control characteristics for optimum efficiency.

In taking decisions he must consider the sensing devices and controls, the plant itself, and the action of the automatic controller.

Direct and indirect control in highly mechanized plants

Figure 2

TRANSFER-LINES FOR MACHINING ON SEPARATE ARTICLES

Transfer-lines[3], as used in the motor-car industry, represent the advent of 'process' production in engineering, and can best be considered alongside, say, glass-bulb making on the 'Corning Ribbon' machine, cigarette-making, or oil-refining.

A transfer-line in the motor-car industry is a series of automatic single-purpose machine-tools linked by automatic transporters. The early transfer-lines were operated by a man at a control panel, who started the new cycle when he was informed by light signals that the previous cycle had been completed; but fully automatic working is now common. Once a line is set up it needs little direct service apart from a change of tools at set intervals. But the dimensions of the finished parts (cylinder blocks, pistons,

Reproduced by courtesy of R.N.U. Renault.

A transfer-line for machining cylinder-blocks (1952). The operator is waiting to initiate a new cycle. Many such lines are now fully automatic in operation.

Reproduced by courtesy of R.N.U. Renault.

The operator is carrying out a sample inspection on a cylinder-block transfer line. He will adjust the appropriate machine if necessary.

etc.) must be kept within their tolerances, and stoppages must be kept to a minimum. In a typical case this is done by a patrol inspector and a setter, who walk up and down the line, observing, taking measurements and making adjustments where necessary. In its general demands the work is similar to that of process operators described on page 11. The men are however skilled craftsmen, but they also seem to acquire a considerable degree of specific control skill (see page 14), finding ways of maintaining quality in spite of idiosyncrasies and defects in the machine-tools. Like process-operators, they seem to exercise greater influence than their formal training would merit. The control work is easier than that on large manually-controlled process plants because a transfer-line can be stopped at any time and the effect of an adjustment is more quickly apparent. The operation of many transfer-presses, bottling and packing plants and automatic assembly lines, presents similar demands.

Reproduced by courtesy of Samuel Courtauld & Co. Ltd.

A weaver at work on an automatic loom. One weaver may have charge of up to 64 looms.

SMALLER MACHINES OPERATING AUTOMATICALLY

Many industries use smaller self-operating machines, for example, automatic looms, packing machines, cigarette-making machines, automatic lathes, and small transfer presses. Here the operator may have charge of two or more machines, dividing his time between them. Any single machine requires to be kept in adjustment in the manner described on page 20, but the consequences of a single breakdown or loss of quality are less serious than on larger plants. Also the work may be easier because smaller machines usually respond more quickly to their controls. But control skill may still be quite important. The operator does not usually keep a log, and his function of reporting to management is less important, but he does have to keep in touch with the maintenance staff. The chief difficulty of this type of work probably lies in the need to divide attention to keep track of the state of affairs in several separate machines, and skill is needed to select the best sequence of actions when faults develop in more than one machine at a time. An example may be taken from a relatively new and expanding branch of the packaging industry.

Case 4. A polythene bag machine operator

The machine makes polythene bags from tubular film by sealing it across at regular intervals and cutting off the sealed sections. The film, made from granular material by extrusion, is first printed with the required pattern (if any), reeled, and stacked near the machine. The reel is then loaded on to a spindle and the double film runs through feed-rollers on to a large rotating cylinder, where the seal is made by the pressure of a heated bar. The film travels round the cylinder and over more rollers to a rotating guillotine which cuts it across near the seal. Finished bags are ejected on to a sorting table at a rate of about one a second, and are then counted and inspected for quality.

Batches, to meet orders for a few thousand to a million or more, are made to a specified length, width, thickness and printing, and each batch is usually completed on the same machine. There are several similar machines grouped together, and each operator runs either one or two machines. A two-shift system (6 a.m.–2 p.m. and 2 p.m.–10 p.m.) is worked.

The operator's job is to set up the machine for each new order as instructed by the foreman, load up and thread reels, start up, and then keep the machine adjusted to produce bags of the correct dimensions until enough of them have been made to fulfil the order. The bulk of his time is spent monitoring the output and making appropriate adjustments. He can alter machine-speed, tension on the reel, relative positions of cut and seal, bag-length, thermostatic sealing-bar temperature, pressure of the sealing bar and lateral position of the film. An automatic control is provided for the lengthwise print position, using a photo-electric scanner to locate a reference mark in the print and a control-unit to adjust it in relation to the sealing bar. The operator sets up the scanner and adjusts the control characteristics to suit the particular printed design and running speed. Coloured lights show when the automatic control is active and the operator can override it if desired.

The usual pattern of working is as follows. The operator looks in turn at the bags coming off the machine, the

cylinder, and the film being fed in, searching for signs of departure from the desired conditions. At intervals he will take off a bag, measure it and test the seal by hand. When any one of the dimensions gets near its permitted limit, he adjusts one of the controls mentioned above to bring it back to the middle of the range, checking again to see that the control has had the required effect. If he cannot get it right, or if more serious faults arise, he may go and seek help from the foreman or the maintenance staff, stopping the machine if necessary. The operator can only leave his machines running unattended for very brief periods, but a neighbour will take on an extra machine for a short time in case of necessity.

Efficient performance seems to depend largely on regular and careful attention and sensitivity to small changes. But there is also some skill involved in successful use of the controls, since several of them interact, for example, increased speed gives less time for sealing and so the bar must be hotter. As compared with larger plant the response to control action is relatively quick and the machine can always be stopped in case of doubt or if anything appears to be going wrong. Though there are no written instructions, individual operators and supervisors have gained in course of time considerable experience of the best setting to use for different orders. This considerably reduces the amount of trial and error needed to get a new order running smoothly, but it does not relieve the operator of the need for systematic checking and re-adjustment. A good operator, who can secure maximum output and minimum waste, may make a difference between profit and loss on an order in a competitive market.

OTHER JOBS IN FLOW-PRODUCTION

Manual operators paced by the machine

At an intermediate stage of development, before fully automatic methods have been developed, operators are sometimes employed on feeding components into continuously running machines or doing particularly fine manipulation connected with them. For instance, work-pieces are loaded into most transfer-machines by hand. However an example of a more skilled job is now described.

Case 5. The straight-line weigher

In filling soft packets of tobacco by machine, the weighing is carried out by two groups of operators sitting on either side of a weighing unit. In front of each girl is a scale-pan and pointer with the correct weight indicated by a coloured panel. She selects a portion of tobacco as near as possible to the correct weight, places it in the pan, and tops it up until the pointer shows the correct weight. At regular intervals the contents of the scale-pan are automatically tipped down a chute into a bucket on an

Reproduced by permission of the Imperial Tobacco Company (of Great Britain & Ireland) Ltd.

Weighing out fine-cut tobacco on the straight-line weigher. A scale indicator is located in the arched opening above the hands of the girl in the foreground, who is dropping tobacco into a scale-pan.

endless conveyor. The bucket moves on and is emptied on to a paper, which is then formed into a packet and sealed in successive stages. If the scale does not indicate the correct weight, the pan fails to discharge, the bucket passes by empty and the operator can then correct the amount during the next cycle. Thus no materials are wasted.

Jobs of this general type require manual or sensorimotor skill, but carry little responsibility. In this example, the machine runs at a moderate speed and failure to keep up with the pace of the machine does not result in waste of material. In other cases, however, machine-pacing may restrict the operator to a uniformly high tempo, allowing little latitude for the variations of pace natural to human beings at work. Such jobs are less satisfactory than either unpaced semi-skilled work or process-operating. Happily they are not common and tend to be eliminated as full automation is achieved.

Visual inspectors of the output from flow-production plants

Where appearance is a criterion of quality, or where faults cannot be sensed by existing electrical or mechanical devices, the output of large-scale process plant may have to be inspected visually. This can often be done on a random sampling basis (statistical quality control). But where 100 per cent inspection is necessary demands may be made on the viewer, because of the need to keep pace with the process. An example is taken from the glass industry.

Case 6. Visual inspection of glass bulbs

> Glass bulbs for electric lamps and valves are produced on the 'Corning Ribbon' machine at the rate of about a million a 24-hour day. The clear bulbs coming off the machine are inspected on a sampling basis. Every five minutes an inspector takes 50 bulbs at random from the belt and inspects them for visual faults; she then takes 5 more and measures their dimensions. According to the number of faults found, the whole of a batch is accepted or rejected.
>
> A proportion of the output is frosted to make pearl bulbs. Trays of 100 are automatically filled and passed through the frosting process. All frosted bulbs are then inspected for visual faults associated with the etching process—small flaws, splashes, or minute cracks—by four girls who view the bulbs both from above and below as they pass in trays, and pick out faulty ones.

In most such cases the work is just like visual inspection in conventional factories, except for the numbers of items involved

and the need to keep up with a moving belt. Similar problems of maintaining quality standards and stabilizing the rate of rejection arise from the fact that human beings find it difficult to maintain absolute standards in qualitative judgements[4]. Where the rate of rejection is very low, the problem of maintaining standards may be acute.

Reproduced by permission of Glass Bulbs Ltd.

Inspecting frosted glass bulbs for small cracks and flaws.

III. PROGRAMME-MACHINES

The number of high-speed digital computers used in business applications, such as computing payrolls and controlling stock, has increased rapidly in the last year or two, but the number of staff engaged in operating them is still small. Nevertheless their skills are worth considering because they represent another distinct pattern of automation.

Reproduced by permission of Leo Computers Ltd.

The operator is checking the result being produced by a large digital computer. The programme and data are fed in at the far left-hand black box, and the computation is set going at the control desk facing the computer.

The advantage of a digital computer over other systems for processing information is that it combines speed and flexibility. It can be switched in a few minutes from computing, say, a payroll, to working out a railway time-table. The principle that makes this possible is the use of a coded *programme*. The machine gets full instructions for each new computation from punched tape or cards prepared beforehand, and so very little time is needed for resetting.

The programming principle has also been applied to the operation of machine-tools, for example, milling machines, lathes, and borers, used for machining complex parts in the aircraft and heavy electrical industries, and for die-sinking in the motor-car industry. Up till now, this type of work has been the province of

skilled craftsmen. The programme for an electronically-controlled milling machine, for example, consists of a series of three-dimensional co-ordinates which define the beginning and end of each flat surface and give a series of points on each curved surface to be machined. When set going, the control mechanism guides the cutting tool to each point in turn, and causes it to follow a smooth path in between by fitting a curve to three or more points. Here again programming makes it feasible to change rapidly from one type of work to another; and accurate complicated work can be done reliably without the services of a skilled machinist, thus economizing in skilled manpower and time.

Reproduced by permission of Ferranti Limited.

A three-dimensional milling machine fitted with electronic control. The programme is fed into the console on the right on magnetic tape. It is read off step by step and a small built-in computer passes instructions to the cutting head.

Up to now little experience has been gained with electronically-controlled machine tools in routine production, for the high initial cost of equipment forbids their use except for very specialized work. A less complicated form of programming has also been applied to looms—the Jacquard loom is perhaps the earliest example of a programme-machine—and to flame-cutting

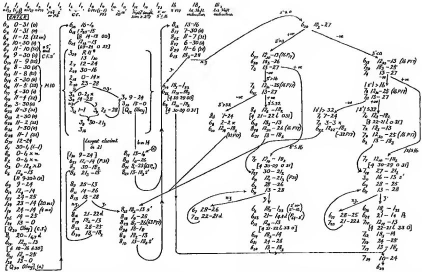
machines, knitting machines, cement-mixing and so on. Ultimately programme-machines may be more widely adopted in those industries where the numbers of complicated parts produced are too small to justify the cost of single-purpose machinery. Their characteristics can only be guessed, at the moment, as very few of them are in use for routine operations. But they appear to make rather similar demands on the operator to those made by computers, the main differences being that they require a skilled machinist to set up the actual jigs and tools, and present much less serious maintenance problems.

THE WORK OF THE PROGRAMME-MACHINE OPERATOR

The operator of a programme-machine is given a schedule of computations to be done or pieces to be machined, and works his way through it as quickly as he can. Each item or group of items requires a fresh programme, that is, a roll of tape or a set of cards. He takes it from the 'library' and feeds it into a reading head, followed by the data for the current computation, which has already been coded for him. He may have to alter some of the switches or settings for each new job. Then he starts the operation by pressing a button, and proceeds to check that the results coming out are 'in the right street'. (He can never check them completely; in one application of a computer this was attempted, but soon abandoned when all the 'errors' discovered were shown to be human ones made during checking.) If they appear seriously wrong he may re-run the programme, or try altered switching, etc., but usually he must report the fact to the maintenance staff or to a programmer, and wait to have it rectified. 'Built-in' checks of the details of computation are usually provided in the programme.

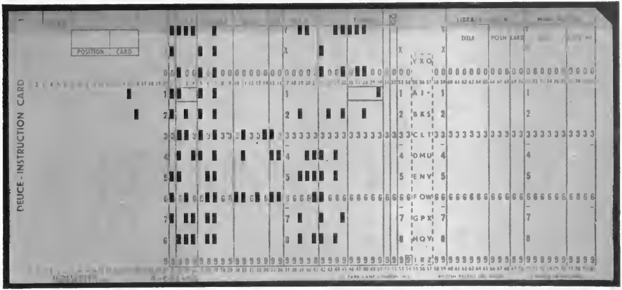
As compared with the process-operator, the programme-machine operator has to do very little monitoring of gauges, and makes few fine adjustments.

The programme-machine operator seems to require neither sensorimotor nor control skills. But he must know enough about the machine's functioning to identify simple faults and recognize its limitations, and he must learn to think in the machine's language. At present computer-operators are mostly young men with a secondary education to G.C.E. 'A' level or beyond but no specialist training. A flexible, logical mind and resourcefulness are



A typical programme for a high-speed digital computer (Deuce). Each entry represents one arithmetical operation to be performed on the numbers for given storage locations. The arrows show which alternative sections are to be used, according to whether the particular numbers are positive or negative, zero or non-zero. The programme can be used repeatedly with different numerical data.

Figure 3 (a)



The programme as fed into the computer

Figure 3 (b)

the main qualifications, and the job can be learnt quite quickly by anyone with these qualifications.

PROGRAMMING

The programmes themselves are prepared by *programmers* whose job it is to break each operation or computation down into very simple steps for the machine and code the result into the machine's 'language'. Programming a computer for a business application is done in two stages. First a specialist at consultant level, known as a *systems analyst*, studies and rearranges the original methods to make them suitable for a computer. The new routines he has devised are then passed on to *coders* who actually programme the sub-routines, thinking out the detailed steps of the computation. In course of time, sets of standard sub-routines are built up, which considerably reduce the amount of detail work. The coder need only have secondary education to about G.C.E. 'O' level (with mathematics) but he or she must be able to think very meticulously. However, automatic methods of programming are rapidly being developed, and the more repetitive coding duties will probably be eliminated in the near future.

DATA PREPARATION

Programme-machines, especially computers, at present depend mainly on human beings to translate the raw data, such as hours worked and stock requisitions, into a pattern of holes on tape or cards. As in the case of other systems based on punched cards, this is done by the *punch operator*. A small machine like a typewriter is used, and a good operator can punch up to seven digits a second. Since errors must be kept to an absolute minimum, each operator's output is 'verified' by a second operator on another similar machine, and the completed cards or tape may even be checked a third time. With all these checks, errors can be kept, in a typical case, down to 20–50 a week for 7 000 000 figures. Similarly co-ordinates from drawings need to be encoded for electronically-controlled machine tools, but the volume of work involved is very much smaller.

IV. CENTRALIZED REMOTE CONTROL

Advances in communication techniques, especially pulse-code signalling and the introduction of reliable 'slave' mechanisms like the dial telephone exchange, mean that the control of widely separated equipment, previously carried out at a number of places, can be now centralized in a 'control room'. The ordinary railway signal-box is an early example of this trend.

The most impressive applications of centralized remote control are found in those public services which operate over a wide area, such as electricity supply, railways, air transport, and telephones, but similar systems are also found within factories for directing the flow of materials, the organization of maintenance effort and so on. The work of a control operator in a railway electricity-supply system will be described by way of example.

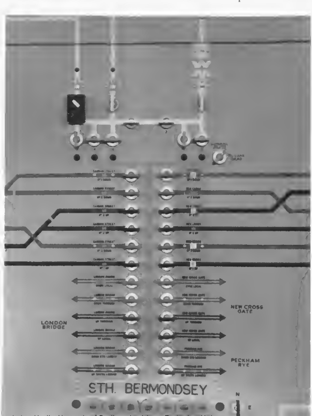
Case 7. Control operator in a railway electrical control room

The 600 volt direct current required for electric trains working on the third-rail system is supplied by converters drawing power from the National Grid at 33 000 volt a.c. Owing to conduction losses, a single converter station can only supply some four miles of track, and so a number of them are needed to supply a complete railway. The older converters were rotary machines. An attendant had to be on the spot to start and stop them; he also operated the switches when necessary, but his time was only partly occupied. The newer mercury-arc converters can be left unattended and can be controlled by remotely-operated switchgear. Some 20–30 of the new converters, with 100–150 associated switches, are now under the control of a single controller and his assistant located in a control room at the centre of a railway district.

The remote switches and indicators, which are connected to those in the sub-stations through an automatic transmission system like a telephone exchange, are laid out in a schematic map on the control-room wall. The controller's desk, provided with meters indicating line voltages, ordinary telephones and a log-book, is placed

Reproduced by permission of British Railways.

(*above*) Layout of a Railway Electrical Control Centre and (*below*) close-up of display panel. The controller and his assistant, seen at their desks, are responsible for all switching operations at the various converter substations shown. Each circle with a bar across it, serves to actuate a single switch. A light comes on within it whenever indicated and actual switch-positions differ.



facing the wall map. The controller's job is to ensure that all tracks are supplied with current when there is traffic, and isolated when idle or when maintenance teams are at work. In case of converter failure, he can cross-connect lines to replace the lost supply from elsewhere. Each converter is protected from overload by an automatic cut-out. When this happens, as it does perhaps two or three times a day in the whole area, the controller has to take quick action. The cause may be a momentary overload from a train starting up, or a chance short-circuit (in one instance a hoop thrown onto the line by children) or, just possibly, a serious accident. The normal procedure is to replace the cut-out twice, and if it still fails to stay in the controller has to find out why. This he usually does by making telephone enquiries to someone on the spot.

There is normally an engineer on duty in the building, and his advice can quickly be sought in an emergency, so the operator does not carry long-term responsibility for judgement in difficult situations; but a simple mistake or oversight on his part can cause serious damage or even loss of life.

THE WORK OF THE REMOTE-CONTROL OPERATOR

As can be seen from the example, the control operator generally has three duties to perform:

(i) *Carrying out scheduled control and working operations.* The demand for public services, such as electricity or transport, follows a more or less regular curve of rise and fall through the day, week, month and year, and this often dictates the pattern of work in a control room. The operator (or his superior) follows a schedule catering for each expected change in demand, observes what the situation is at the time and then makes further changes if the actual position differs from what was expected.

(ii) *Meeting chance demands in his area in the most advantageous way.* Remote-control mechanism limits the operator's scope in dealing with chance demands. This means usually he has a much smaller range of choice than someone on the spot would have. It also limits the amount of information available to him. Thus, when making a control decision he has to select one out of a very

few alternative actions, according to the limited information about the actual situation given to him by symbolic indicators, such as lights and pointers. If the operator wants more complicated information or action than the remote-control equipment can provide, he has to use the telephone.

(iii) *Keeping a log*. Control actions and any unusual events are recorded and if necessary reported verbally to the engineer.

SKILL AT REMOTE CONTROL

The remote-control operator is not a skilled craftsman, he does not exercise sensorimotor skill or control skill of the type needed to run a plant. The main requirement is ability to interpret arrays of indicators, relating them to one another and to the outside situation and to take quick decisions. While he could do this by following fixed rules, there will be far more flexibility if his decisions are based on actual knowledge and understanding of the system being controlled. In the example quoted, the controller appeared to adopt the latter approach, though he dealt with some situations by rule. As a controller cannot build up the necessary mental picture of the equipment, and how it works, from experience in the control-room alone, he must acquire it beforehand. Control operators are therefore often recruited from operators or maintenance workers with experience in the same organization. This is also useful from the social standpoint, as the controller finds it helpful if he is personally acquainted with some of the people with whom he has to deal by telephone.

This type of ability may be described as 'information-handling' skill. Its possessor can quickly evaluate coded information and make decisions between well-defined alternatives within an artificial system.

The skill seems to comprise:

(i) *Selective vigilance*—being receptive to particular signals in the presence of other distracting ones.

(ii) *Translation of data*—relating the symbolic information from remote indicators to the real world.

(iii) *Decision*—reviewing the possible control actions and their consequences and selecting the best for the given circumstances by predicting the consequences of each.

Decision could degenerate into a habitual response, but a skilled operator will not be guided solely by habit.

(iv) *Short-term memory*—being able to remember recent instructions, events and conditions relevant to a given decision and, perhaps equally important, to forget them when out of date.

As yet there is little indication of how far individuals differ in information-handling skill, or what conditions favour its acquisition.

STRAIN OF REMOTE-CONTROL WORK

Apart from skill and knowledge, the power to resist anxiety is important in control-room work. If an operator makes a mistake, it can easily cause injury or loss of life. Yet he must take his decisions rapidly in a highly artificial situation, deprived of the numerous cues which combine to prevent error in the more natural and direct situations of everyday life. Wrong interpretation of signals, lapse of memory, failure to notice a signal, or misunderstanding of instructions, may have serious results. Yet all human beings are prone to make such errors occasionally. If an operator consciously or unconsciously dwells on the possible consequences of a mistake, he may become chronically 'anxious', developing digestive or other bodily symptoms, even though he never actually does make a mistake. Unfortunately it seems that the most conscientious and efficient operators are the most prone to this disorder.

OTHER CONTROL-ROOM WORK

A clear distinction must be drawn between the work of centralized remote-control operators, as discussed above, and that of plant operators, though the latter may also spend a large part of their time in a control-room. The difference is that the plant operator frequently visits and inspects all the equipment under remote control. He can thus both maintain an accurate idea of the situation being controlled and supplement the instrumental indications by direct inspection. A further point of difference is that plant operators are usually concerned with fine adjustments to a single complete process, whereas remote-control operators tend to carry out discrete switching or signalling actions at various separate places.

First Published in Scientific American, *September, 1952.*

A large modern oil-refining unit, seen by night. The unit is operated by a small team working in the control room at the lower right-hand side of the picture.

Remote handling with direct viewing

Another type of remote control is found, for instance, in continuous strip-mill of a steel works, where the roughing mill pulpit operator's job is to pass slabs of red-hot steel back and forth between pairs of rollers by operating the electrical controls of the roller transporter. He sits at a control-panel above the mill, and all his actions are guided by vision, together with verbal messages from other parts of the mill. He exercises remote control over the machinery; his skill is essentially a sensorimotor one, as the expert learns to use the machinery without conscious thought—as if it were an extension of his own body. In this respect the job, and others like it, have much in common with driving cranes or even motor-cars.

Operating a continuous strip-mill also requires process-control skill as described on page 14. The key job, carried out by the 'roller-man' and his assistant, is controlling the width and gauge of the strip.

Reproduced by permission of the Steel Company of Wales Ltd.

The speed operator at work in a continuous hot-strip mill. His job is to regulate the mill drive by means of the long levers. He can see the finishing mill through the window; he refers to the rolling programme in front of him and can talk to other operators by microphone and loudspeaker.

V. MAINTENANCE WORK IN AUTOMATIC PLANTS

While the proportion of maintenance staff to production workers rises steeply as automation progresses, there does not seem to be any marked change yet in the balance of craft skills except that rather more electronic technicians and instrument-mechanics are needed to service the increased amount of electrical control gear. (Table 2.)

PREVENTIVE MAINTENANCE

As plants increase in size and reliability, the balance of maintenance effort is altered by the widespread introduction of 'preventive' or 'planned' maintenance. Its purpose is to minimize the

TABLE 2.

NUMBER OF PROCESS AND MAINTENANCE WORKERS IN A MODERN OIL REFINERY

	Process Workers	Maintenance Workers	Total	Percentage of Total Number of Employees
On shift work	752	64	816	36·3
On day work	114	1319 (622 skilled 697 others)	1433	63·7
Total	866	1383	2249	
Percentage of Total Number of Employees	38·5	61·5		

risk of interruption to the smooth flow of production, and this is achieved by inspecting all parts subject to wear and, if necessary, refitting or replacing during planned shut-down periods, rather than waiting until they fail in operation. The maintenance work can then be better organized than during unforeseen stoppages.

Under this system of maintenance the staff are divided into:

(i) *The day-work force* which is responsible for major overhauls. These overhauls may be carried out entirely by skilled craftsmen, but in some cases it has been found possible to divide the work into a series of more or less repetitive operations resembling semi-skilled work in batch-production, and thus save skilled effort for the more critical items. Incentive schemes based on work-measurement have been applied to this type of maintenance work.

The day-work force is also responsible for some routine maintenance on plant during production. While it is on site, it may be

Reproduced by permission of George Kent Ltd. and Engineering.

Maintenance work in progress on a recorder/controller in a modern automatic plant.

called on to tackle unforeseen breakdowns and to make running repairs.

(ii) *The shift maintenance staff or 'crash-gang'* has some responsibility for routine maintenance, but its major function is to tackle unforeseen breakdowns occurring on the evening and night shifts. Speed is essential here, for shut-down time may be very expensive; if necessary, the team may call for special support from the management, or even call out members of the day-work force.

Shift maintenance staff co-operate closely with shift process operators, but they usually belong to a different department. In an oil refinery, for example, the shift maintenance force (under the shift engineer) belongs to the mechanical department, whereas the operators (under the shift superintendent) belong to the process department.

The day-work force usually numbers far more than the shift maintenance staff. In an oil refinery, for example, there were only 16 on night shift, compared with 1319 on day-work.

DIAGNOSTIC SKILL

It is important, especially during production runs on large plant but also in other critical situations, that the 'crash-gang' should make speedy repairs to unforeseen breakdowns. This means that they need to be especially good at diagnosing the cause of faults and resourceful in curing them. Several strategies can be adopted in tracking down a fault, which are based on a more or less systematic elimination of the various possibilities. One is to test for faults in order of likelihood, and another to eliminate half the remaining possibilities at a time by properly chosen tests. Diagnostic skill probably consists partly in sensitivity to the clues which may be important, partly in interpreting them effectively in relation to the situation, and partly in selecting the most efficient testing strategy.

There appears to be considerable difference in diagnostic skill between individuals, even among those with the same level of technical knowledge.

NEW TYPES OF CRAFT SKILL

It seems likely that two new craft skills will soon emerge, and new apprenticeship schemes may be needed in the near future to cater for them.

'Polyvalent' craftsmen

The traditional division between mechanic and electrician is becoming a hindrance in servicing some modern equipment. For example, in the unit head used on transfer-lines in the motor car industry, the electrical and mechanical parts are closely interlocked, and the craftsman servicing it needs a grasp of both

electrical and mechanical practice. Conventional craft-apprenticeships provide a man with one skill or the other but not both. Apprenticed electricians can be trained in the mechanical side, or vice versa, but for proper balance a mixed or 'electro-mechanical' training will probably be found essential. In France, where the development has already taken place, the term 'polyvalent' is applied to craftsmen with more than one field of competence.

Control technician

Though servo-mechanisms for automatic plant may be actuated by electrical, pneumatic, hydraulic or mechanical means, according to convenience, a common theory of feedback and control underlies them all. At present instrument-mechanics usually deal with them as an extension of their proper field, as there is no recognized qualification in servo-mechanisms as such. Control engineering has recently been established as a distinct discipline at graduate level in the Battersea College of Technology and elsewhere, and a similar innovation may be expected at technician level.

The 'control technician', as he might be called, should have a grounding in the theory of servo-mechanisms and control, in electrical and electronic principles, and in the various practical methods. He should be able to set up and service all the automatic controls and instrumentation on a plant and to diagnose operating faults due to disturbance within control loops.

At the present time it is sometimes not possible to recruit instrument fitters as such; for example at Britain's largest oil-refinery electricians and mechanical fitters are recruited in about equal numbers and are then given intensive training in electronics and the basis of instrumentation. This appears to be a tacit recognition of a new trade on the lines described above.

VI. WORKING CONDITIONS

Through instrumentation and remote control the plant operator is enabled to work away from the actual plant. This is a great advantage when, as in the chemical, food and metallurgical industries, the plant is hot, steamy and emits smoke or fumes.

However, operators must often inspect the plant itself, and then they are exposed to adverse conditions. Even simple applications of automatic control, such as thermostats for ovens and constant-head devices, improve the working environment, not by eliminating harsh conditions but by reducing the time of exposure to them.

ISOLATION

Workers are often more widely spaced apart in automatic plants than in conventional factories (though the reverse is true in control rooms), yet this *physical* isolation does not necessarily mean social isolation. The job usually entails communicating with various people at frequent intervals, and the operator can often leave smoothly-running plant for brief periods. Automatic control helps by reducing the frequency of adjustment and so confers still more freedom. The most serious cases of social isolation seen on the survey were due to noise so loud that people could not talk intelligibly to one another, even at close quarters; this was particularly true of workshops with many smaller automatic machines, such as automatic looms. Noise may also have an adverse effect on work if it hinders essential communication between members of a team. In some situations this may well present a serious problem, to which little attention has so far been paid.

MONOTONY

Process-operating on continuous-flow plants is often thought to be very monotonous, but few complaints were heard on this score. Not many automatic plants are so tightly controlled that nothing at all happens for long periods, and even if this is so the operator is free within certain limits to move about and do as he likes, knowing that automatic warning devices such as hooters and lights will recall him in an emergency. The most monotonous work is found where simple but important process variables are under manual control, for then the operator may have to keep his attention permanently on the job, though the job is not difficult enough to engage his full mental powers.

VII. SUPERVISION

The survey covered mainly work and skills at operator level, but it also included observations concerning supervision. Previous writers have pointed out that the foreman's role changes with automation, and the survey endorsed this view. While the exact position varies widely, it is usually true to say that automation reduces the number of workers supervised by a given foreman, so that this side of his function diminishes in importance. But a more fundamental change stems from the nature of the work being supervised. The worker need no longer exert continuous physical effort to maintain output; instead he monitors a continuous process and, in doing so, seems to acquire a sense of responsibility towards the plant itself and an attitude of mind quite different from that of the semi-skilled worker in mass-production work. He is largely self-supervising, but there is a good deal of indirect supervision as he is in close touch with management, reporting the plant's behaviour and so on. So the need for direct supervision of his work is very much reduced.

The foreman's position tends to become equivocal. If he possesses sufficient technical skill and knowledge, he may act as a roving technical adviser; and if he has also the necessary personal qualities, he may become the accepted leader of an integrated team. But, however good he is at managing men, unless he has extensive technical knowledge and experience, he is apt to find himself a fish out of water, merely keeping records and arranging rotas. Where there is a qualified engineer on each shift, it is doubtful whether there is a place for him at all.

In short, the evidence from the survey suggests that the place and purpose of first-line supervision in automatic plant needs further study and rethinking.

VIII. RESPONSIBILITY AND SOCIAL SKILLS

RESPONSIBILITY

Most managers of automatic plants visited during the survey stated that their plant operators must be 'responsible' men, but it was not always clear just what they meant. As applied to the production worker the term 'responsible' seems to have one or more of the following meanings:

1. *Responsible*—able to make satisfactory judgements on matters of discretion, so that his work does not need frequent checking by superiors. (One research worker(5) has proposed that the 'time-span' elapsing before work is checked is a good measure of the 'level' of responsibility.)
2. *Conscientious*—ready to take extra trouble and care, without direct instructions, when the situation demands it.
3. *Reliable*—never making mistakes, forgetting instructions, overlooking important indications etc. or otherwise failing in his prescribed duties.
4. *Trustworthy*—honest and truthful in reporting to superiors; not concealing the facts when his own actions may have had adverse effects.

These traits are by no means always found together; for instance a stable personality of low intelligence may be 'reliable' but not 'responsible'. On the whole, it seems that 'trustworthiness' and 'conscientiousness' are most sought after for the lower grades of process-operator, but 'responsibility' and 'conscientiousness' for the higher grades.

Programme-machine operators need good judgement (responsibility). Remote-controllers must be 'reliable' since a single mistake may be disastrous.

Managers also very frequently mentioned that their operators were chosen partly for their interest in the job. It seems that without this quality which provides an incentive to find out what is happening and why, the operator would be much slower in learning the job.

Although workers in an automatic plant seem at first sight to be isolated, closer study reveals a surprising amount of inter-communication between individuals operating the machinery. Each member of the team—operators, maintenance men, engineers and laboratory staff—frequently gives and receives information or instructions about the plant from the others, by word of mouth, in writing and even sometimes by hand-signals. It seems that the efficient running of a plant depends a great deal on the effectiveness of these interchanges. Therefore, each member of the team must be able to communicate easily with his fellows, understand their points of view and put his own across. In other words, they must exercise *social skills*. As yet no serious attempt has been made to identify or analyse these skills further, but perhaps it is significant that management want their operators to be 'good mixers'; for personal acceptance and friendship ease communication at work. There is no place in an automatic plant for the 'no-talking' rule; in fact the more talking, within limits, the better.

IX. SOME PERSONNEL PROBLEMS FOR MANAGEMENT

SELECTION OF OPERATORS

Labour turnover is low in automatic plant, because relatively few operators are needed and because the jobs are often desirable. Numerically, therefore, personnel selection presents only a small problem. But the jobs are key ones and a mistaken first choice of a recruit may prove disproportionally troublesome later on. At present most managers select promising men from the firm's labour pool and put them on the plant as trainees for a trial period. Even so, it is difficult to assess a potential operator's real aptitude for control work, still less the hidden factors in his personality.

Psychological aptitude tests have had some success in other fields and they could presumably help to assess aptitude for control work and capacity for responsibility, as defined above, so forming the basis for a more scientific approach. So far none of the existing tests has been proved valid for this purpose, except that a minimum level of general intelligence can be laid down for many classes of job. The first step in the right direction would be to administer a number of the standard tests to operators on various control jobs and find out which gave the best agreement with their measured performance or with supervisor's ratings. New tests would then need to be developed to fill in the gaps, and a 'battery' of tests assembled which would enable employers to predict a recruit's future performance.

TRAINING

A recent survey[(6)] has shown that systematic operator training is exceptional even in non-automatic plants in this country; in automatic plants it is rarer still, probably because the processes need fewer new operators. It is often set up when new plant is being commissioned, but tends to lapse soon afterwards for lack of demand. Elsewhere basic courses for process-operators are run at infrequent intervals. Such schemes usually provide formal instruction on the process, nomenclature, elementary science, safety and so on, but hardly any attempt has been made to

inculcate working skills as described above, and in practice these are invariably acquired on the job by working alongside experienced operators. While this procedure can be fairly satisfactory, it leaves much to chance, and many costly breakdowns may be attributed to inadequate training of operators.

Since the last war a strikingly successful method of training for repetitive skills has been developed in this country.(7) The first step in this method is to make a careful analysis of the experienced worker's performance; then sections of the job are practised, using the experienced worker's method and making his speed a 'target time' for the trainee; the separate sections are then combined progressively to make a complete cycle, performed at the experienced worker's speed. The method, known as 'specialized operator training', cannot be applied as it stands to control jobs because the work is neither manual nor repetitive.* But a similar analytic approach may well lead to an effective method of training for the new skills, if a substitute can be found for practice by progressive combination of parts of the job. This poses problems for future research. Work is also needed on methods of retraining older workers made redundant by changing technology.(9)

PAYMENT AND INCENTIVES

Financial incentive schemes based on time study are widely applied in unit-and mass-production industry, and some managers have sought to apply them to plant-operation. However, the stop-watch is of little use, because the time spent in physical work is so small. Conventional incentive schemes cannot be used, as the operator's effectiveness is not at all closely related to high speed or effort. Yet plant operators may feel unfairly treated when they compare their moderate flat-rate pay with the high piece-rate wages that some semi-skilled operators or labourers can earn on the plant.

A different approach, known as the multi-factor incentive scheme, is to measure performance in terms of yield, quality and other factors, combining them into a single index, weighted

* A recent study(8) sponsored by the European Productivity Agency deals more fully with training for automatic processes.

according to importance, and then to pay a bonus according to the index figure achieved each week. The operator then has a direct incentive to do better at his job. But the difficulties of assessment and weighting are so great that very few such schemes have been applied and these have achieved mediocre results.

Two other systems of payment are in use, but neither of them is based on direct measurement of work done. The first—merit-rating—gives bonus pay according to the supervisor's assessment of performance, and the second—job-evaluation—allows basic rates to vary with the difficulty of the job, giving operators on more difficult plant a higher rate. Both of these systems depend on subjective judgements of merit or difficulty, and disputes about whose judgement is right are apt to arise. Attempts have recently been made to put job-evaluation for control work on a more objective footing. If they succeed, they may well provide a satisfactory solution. However, the whole problem may be superseded if, as seems at least possible, piece-rates are gradually abandoned throughout industry in favour of high time-rates.

X. CONCLUSIONS

The most impressive finding of the survey concerned continuous-flow production plants. Although the term 'automation' has only been applied to some of them, notably transfer-machines and automatically-controlled plant in the oil industry, they have a common pattern of work and skill. The work comprises *control*—monitoring and making adjustments to secure good yield and quality—and *communication*—logging instrumental readings and reporting to other members of the operating team.

The first of these elements requires 'control skill', which is usually specific to one situation and can only be acquired by experience. Its chief component is decision—selecting the best control action for each combination of circumstances that arises. The less good operators tend to work by 'rule of thumb', the better ones by an intuitive appreciation of the state of affairs, possibly using a mental 'working model' of the process. Logical thinking seems to be less common than might be expected. While the trained engineer may use logical thinking to solve plant problems, the ordinary operator appears to behave more intuitively. Yet oddly enough the operator can sometimes achieve better results than the engineer. This can probably be put down to his ability, derived from intimate experience of the plant, to take into account the many ill-understood factors which affects most plants' running but which he cannot communicate to his engineer. It seems that the rational approach cannot adequately handle complicated events and intuition must take over.

Repetitive manual jobs, though virtually abolished in production, tend to reappear in the guise of planned maintenance. Hence the difference between the type of work done by *daywork* and *shift* maintenance staffs is growing steadily wider. The latter must be able to deal rapidly with unforeseen breakdowns and may need 'diagnostic' skills as well as their regular craft training. New maintenance skills will probably emerge—the 'electro-mechanical' fitter for servicing modern types of machine-tool, and the 'control technician' for servo-mechanisms and control devices.

Lack of information precludes a proper estimate of the numbers in each type of occupation mentioned here. Plant operators in continuous-flow production are certainly the biggest group, but

even in the most advanced process industries (and allowing for shift working) they do not amount to a half of the total labour force (see Table 2 page 46).

The introduction of automatic methods leads to an increase in output per head, and to a reduction in the number of direct production workers. However, as the changeover from conventional to automatic methods is made in stages over a period of time, and is accompanied by an overall rise in production, redundancy does not present as serious a problem as is sometimes feared.

Taking the country as a whole, only a tiny fraction of the labour force is employed on operating automatic plant, though the plant itself forms a relatively large part of the country's productive capital equipment. Thus the efficiency of these few operators has an economic importance disproportionate to their numbers and it would seem worthwhile to intensify study of the factors affecting it. Subjects particularly worth studying are: methods of personnel selection; training techniques for specific-control skills; principles of equipment design for effective human use; and types of social organization, team structure and leadership most fitted to operate different kinds of process.

This short report can only sketch the outlines of a picture. It glosses over many subtle differences of work and skill within the categories described and the industrial reader will undoubtedly question from his particular experience the content and emphasis of some of the statements made. Since there is as yet little accredited knowledge on the subject, the survey can be counted a success if his questionings lead the reader to fruitful discussion and further investigation.